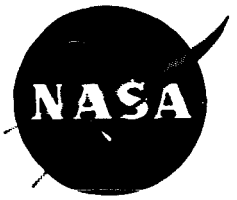
THIRD QUARTERLY REPORT

FOR

STUDY OF NICKEL-CADMIUM CELLS

(17 November - 17 February 1966)

Contract No. NAS5-9586



Prepared By

Research and Development Center
General Electric Company
Schenectady, New York 12305

Prepared For

Goddard Space Flight Center
Greenbelt, Maryland

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SUMMARY

The work being performed under this contract consists of two phases: 1) a detailed study of the behavior of the positive nickel hydroxide electrode with respect to its charging characteristics, gassing behavior, and charge retention; and 2) a study of the sources and effects of impurities on the performance of nickel-cadmium cells. This program is an extension of the work on the characterization of nickel-cadmium cells conducted under a previous NASA contract (NAS 5-3477). The overall goal of this work is the development of nickel-cadmium cells with more uniform capacity and operating characteristics, such as charge and discharge voltage, charge acceptance, pressure behavior during charging, and cycle life.

During the third quarter, an additional two hundred positive electrodes were processed through the initial six cycle, charge-discharge, characterization procedure. An analysis of the resulting capacity data indicates a representative capacity distribution curve for the lot of positive electrodes being used in the program has been obtained. The capacities for the three hundred electrodes processed to date, range from 950 ma.-hrs. to 1350 ma.-hrs. Ninety percent of the electrodes have capacities between 1050 to 1250 ma.-hrs. There are an approximately equal number of electrodes in each of the four 50 ma.-hr. capacity increments between 1050 and 1250 ma.-hrs.

The positive electrodes behavior studies are underway. Six electrodes, three from the high end (1201-1250 ma.-hrs. increment) and three from the low end (1051-1100 ma.-hr. increment) of the capacity distribution curve, were cycled from six to twelve times in the 100% depth of discharge mode (charge and discharge rates -300 ma.). The voltage versus a reference electrode (mercury-mercuric oxide) and the rate of oxygen evolution were measured and recorded during these cycles. The voltage data has not been analyzed. The gas evolution data has been analyzed by examining plots of the instantaneous percentage of charge current being converted to oxygen versus a state of charge factor for the electrodes. The state of charge factor is defined as the ampere hour input minus the ampere hour converted to oxygen up to any time during the change period divided by ampere hour capacity obtained on the discharge portion of the cycle. All electrodes showed measurable oxygen evolution (1-2% of charge current converted to oxygen) at approximately 50% state of charge. At a 90% state of charge, the gassing rate values for the two groups of electrodes overlapped. The gassing rate values in the twelfth cycle were in the range of 5 to 7% at a state of charge factor of 90%. One trend observed was that all of the electrodes showed a transient increase in gassing rate during the second to fifth cycle and then a gradual decrease in gassing rate with continued cycling. Another significant observation is that all of the electrodes increased in capacity over the twelve cycles. Electrodes from the low capacity group increased approximately 10% and those from high capacity group increased 3 to 5%.

After the twelfth cycle, the electrolyte in the test cells was made approximately 0.3M in carbonate by bubbling carbon dioxide through the electrolyte. The electrodes were put through six additional cycles. Although the data has not been analyzed in detail, there were no significant changes noted in capacity or gassing rates.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

Section 1

INTRODUCTION

This report covers the work done during the third quarter of the contract, 17 November 1965 to 17 February 1966. The results of the work performed under a previous contract (NAS5-3477) on the characterization of nickel hydroxide and cadmium electrodes shows that, to a great extent, the variable or erratic behavior of the nickel-cadmium cell can be assigned to the behavior of the nickel hydroxide electrode. A second major contributing factor is the presence of impurities introduced into the cell either during its manufacture or formed as degradation products from cell components during the operation of the cell.

The objective of this program is to determine the relative importance of these factors and the extent to which the variability in cell performance can be reduced. The experimental work includes detailed studies of individual positive electrodes and cyclic sealed cell performance tests.

During the third quarter, the initial characterization of positive electrodes was continued. An additional two hundred electrodes were charged and discharged for a total of six cycles at a rate of 300 milliamperes (nominal c/4 rate based on the capacity of the positive plates). A total of three hundred positive electrodes have been processed in this manner.

Potential time curves for each electrode are recorded during these cycles. From these curves, the electrode discharge capacity and graphitic capacity are determined. The data for each electrode is averaged for the six cycles and these values are the initial discharge and graphitic capacity for the particular electrode. The individual capacities for each of the six cycles are fitted to a straight line and the slope and standard deviation calculated to note differences in electrodes. These computations are made on a computer. An additional program is then used to classify electrodes into 50 ma-hr. capacity groups and in order of increasing slopes of the capacity vs. cycles curves. In this manner, electrodes having similar characteristics in a given capacity group can be selected for use in the positive electrode behavior studies. A plot of the number of electrodes in each discharge capacity group of 50 ma-hr. range provides a distribution curve.

The positive electrode behavior studies are underway. Three electrodes, each selected from the high and low end of the capacity distribution curve, were cycled in the oxygen evolution rate measuring facility in the 100% depth of discharge mode at room temperature. Charge and discharge rates for these tests are 300 ma. During the tests, the electrode potential versus a reference electrode is monitored and recorded along with the concentration of oxygen in the nitrogen carrier gas stream flowing through the test all. Capacity and gassing rate variations for these electrodes were monitored for twelve cycles. Subsequent to the twelfth cycle, carbonate was added to some of the test cells and cycling was continued for six additional cycles. Details of these experiments are given in the following section.

Section 2

DISCUSSION OF RESULTS

DISTRIBUTION OF ELECTRODE CAPACITIES

Two hundred positive electrodes were processed through the initial six cycle characterization procedure during the quarter. The electrodes are charged and discharged at a rate of 300 ma (nominal c/4 rate). The discharge capacity of each electrode is defined as the average of the values for the six cycles.

The electrode capacity distribution based on 50 ma. hr. increment ranges of capacities is shown in Figure 1. The distribution is plotted in a cumulative manner showing the effect of successive groups of 100 electrodes. On the basis of these results, it appears that a representative sample of the 1000 positive electrode lot has been obtained. An additional one hundred electrodes will be processed to provide a sufficient supply of electrodes from which electrodes will be selected for use in the positive electrode behavior studies and the impurities studies.

The detailed data for each electrode characterized is recorded in the Appendix, Table I-1. The data includes the average discharge capacity for the six cycles and the slope of the line passing through each capacity step. Similar data is recorded for the graphitic step. The data is presented in groups of discharge capacities having 50 ma. hr. increments.

A comparison of the characterization capacity data for the electrodes (Schenectady) with the capacity values determined at Gainesville is shown in Table 1. The values shown are the averages for groups of 10 electrodes. The 10 electrodes constitute a cell pack which was used in the electrochemical testing at the Company's Gainesville, Florida Plant. In the majority of the cases, the Schenectady values are within five percent of the Gainesville values.

In one case, cell pack number 9, the Schenectady value is 36% higher than the Gainesville value. This large change suggests that the original pack was incompletely formed.

In the last quarterly, it was observed that capacity increased with repeated characterization cycling. A similar observation has been noted in the positive electrode gassing behavior studies. In view of these results, it is now planned to recharacterize approximately 100 electrodes, 50 selected from the high and 50 selected from the low end of the capacity distribution curve for an additional 25 cycles. The capacity data will be correlated to see if the shifts in capacity distribution is significant for the two groups of electrodes. These electrodes will then be used in the positive electrode behavior and impurity studies. Results will be compared with electrodes from the same group, but only characterized for 6 cycles.

Figure 1. Positive Electrode Capacity Distribution Curve.

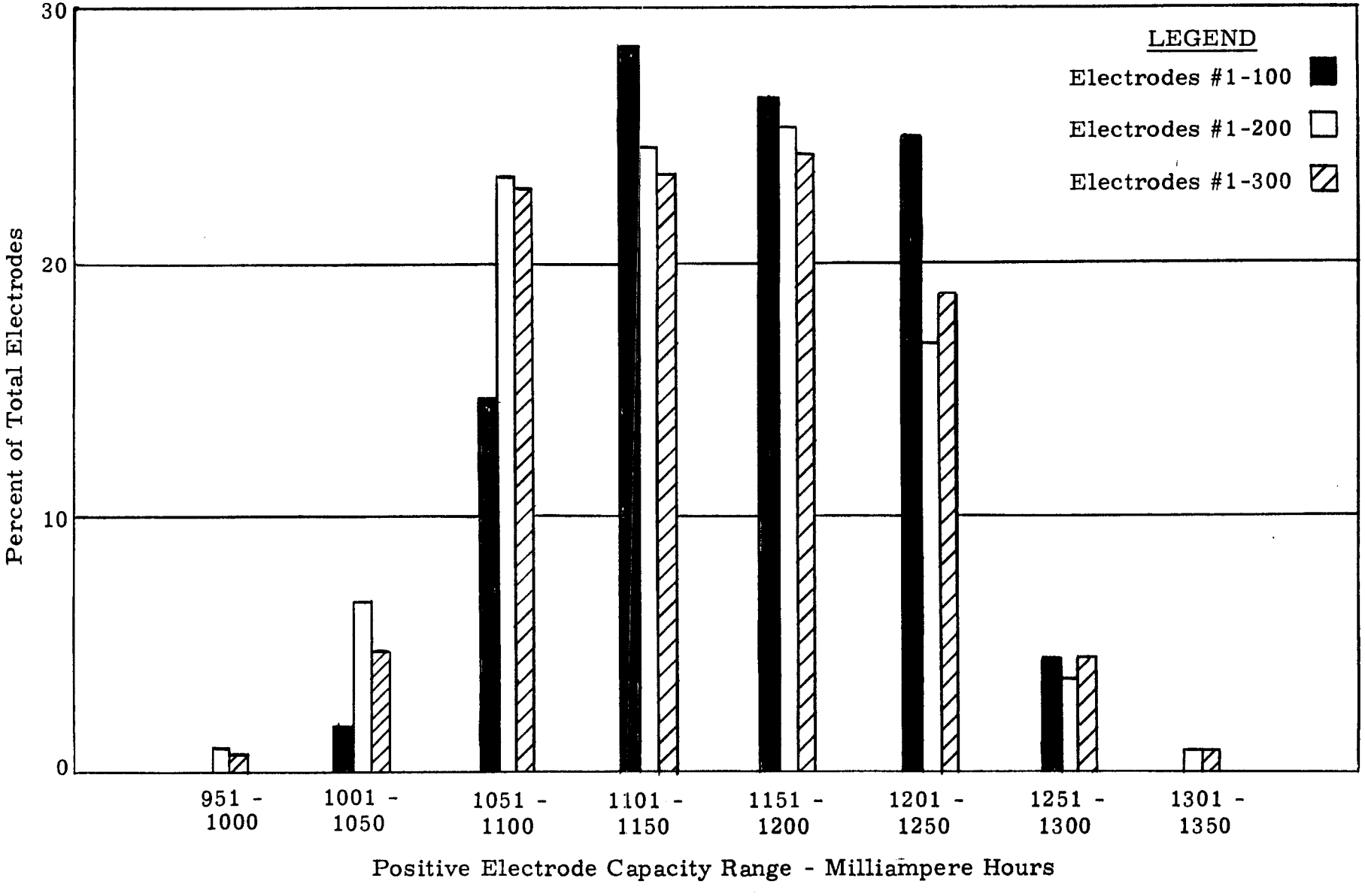

TABLE 1

CHARACTERIZATION DATA SUMMARY

Electrode Number	Plate Batch Number	Cell Number	Gainesville Average ma.hrs.	Schenectady Average ma.hrs.
1-10	2	22	1105	1138
11-20	2	34	1183	1196
21-30	2	36	1042	1125
31-40	3	2	1081	1144
41-50	3	19	1149	1197
51-60	3	25	1037	1153
61-70	4	19	1134	1224
71-80	4	10	1164	1161
81-90	4	21	1091	1128
91-100	5	6	1073	1107
101-109	5	9	873	1188
111-120	5	10	1139	1178
121-130	5	2	1109	1138
131-140	5	3	1057	1111
141-150	5	4	1042	1094
151-160	5	5	1057	1103
161-170	5	7	1123	1126
171-180	5	8	1123	1116
181-190	5	1	1130	1114
191-200	4	1	1120	1100
201-210	4	2	1154	1160
211-220	4	3	1134	1131
221-230	4	4	1134	1160
231-240	4	5	1096	1122
241-250	4	6	1120	1135
251-261	4	7	1134	1155
281-290	4	11	1120	1141
291-300	4	12	1139	1143
301-310	4	13	1164	1220
310-320	4	14	1105	1139

POSITIVE ELECTRODE BEHAVIOR

The objective of these studies is to determine the capacity, voltage and gassing behavior of individual electrodes as a function of the state of charge in selected cyclic modes of operation. Variables which will be examined are the initial characterization capacity and the effect of extensive cycling of the electrode. Details of the cycling modes and test conditions are given in Table 2.

The experimental equipment for measuring and recording the rate of oxygen evolution is described in the second quarterly report. At the present time, it is planned to monitor oxygen evolution up to the point where the electrode is 90 to 95 percent charged. The electrode is charged beyond this point, with the total charge equal to 120% of the nominal capacity on each cycle.

During the quarter, six electrodes were examined with the electrodes being cycled in the 100% depth of discharge mode at room temperature using a charge and discharge rate of 300 ma. Three electrodes were selected from the high end of the capacity distribution curve (1201 - 1250 ma. hr. range) and three electrodes from the low end of the curve (1051 - 1100 ma. hr. range). The electrodes received from six to twelve cycles, in some cases intermittently. Following the twelfth cycle, some exploratory experiments were made to note the effect of carbonate addition to the electrolyte.

A summary of the capacity data obtained during the course of the cycling is given in Table 3. The most significant observation is that in all cases except one (electrode No. 45), the electrode capacities increased over the course of the cycling. The electrodes from the low characterization group (1051 - 1100 ma. hr.) showed the largest increase in capacities, ranging from 137 to 177 ma. hrs.; whereas, the electrodes in the high capacity group (1201 - 1250 ma. hr.) showed increases of 29 to 55 ma. hr. Similar increases in capacity were observed during the previous quarter for electrodes which were put through the characterization cycling procedure a total of four times.

Analysis of the gassing data is being made on the basis of plotting the percentage of the charge current converted into oxygen at a given time versus the state of charge of the electrode at the same time. The state of charge of the electrode is defined as:

$$\text{State of Charge Factor} = \frac{C_t - C_g}{C_d}$$

where

C_t = the total ampere hour input to the electrode up to time t.
C_g = the ampere hour equivalent of all the gas evolved up to time t.
C_d = the capacity delivered by the electrode on the discharge subsequent to the gas measurement run.

TABLE 2

POSITIVE ELECTRODE BEHAVIOR TEST PLAN

Test Mode	Temperature (°C)	Charge and Discharge Rate	Open Circuit Stand Time (minutes)	Remarks
Cyclic Tests				
1. 25% Depth of Discharge	0 and 25	C/4 - c/4 C/4 - c/4	15 to 120	Periodic capacity measurement
2. 100% Depth of Discharge	25	C/4 - c/4	15 to 120	--
Open Circuit Decay Tests Starting State				
1. 75% charged	25	C/4 - 0	--	Monitor voltage decay and oxygen evolution rate. Residual capacity measurement at fixed intervals of time.
2. 100% charged	0 and 25	C/4 - 0	--	
3. 125% charged	25	C/4 - 0	--	
4. 150% charged	25	C/4 - 0	--	
5. 200% charged	25	C/4 - 0	--	

TABLE 3

POSITIVE ELECTRODES CAPACITY DATA SUMMARY

Electrode Number	Initial Capacity ma. hrs.	Capacity[3] vs. Cycle Number 1	2	3	4	5	6	10	12	14
45	1203	1144	1161	1162	1141	1162	1162	--	--	-- [1]
128	1235	1230	1245	1250	1257	1260	--	--	1290	1290[2]
74	1240	1194	1230	1230	1230	1236	--	--	1269	1269[2]
82	1063	1144	1161	1180	1160	1240	1240	--	--	-- [1]
141	1053	1035	1080	1104	1110	1125	--	1176		1200[2]
121	1093	1050	1104	1116	1128	1146	1155		1230	1230[2]

NOTES: [1]Electrodes cycled six times, two cycles consecutive with several days rest between cycles 2 and 3, and 4 and 5.

[2]Electrodes cycled twelve times, six cycles consecutive with several days rest between cycles 6 and 7. Carbonate added to 31% KOH electrolyte after cycle number 12 by bubbling CO_2 through electrolyte. Cycling was continued for six more cycles.

[3]Capacity in ma. hrs.

Data for the electrodes are plotted in this manner in Figures 2 through 6, for some of the cycles to illustrate the order of magnitude of gassing rate and variations observed during the course of the cycling. Data points for these curves are given in the Appendix, Table A-2.

There is insufficient data at this time to draw any quantitative conclusions with respect to differences in gassing behavior. Qualitatively electrodes which were cycled twelve times showed a common pattern in the shifting of the curves shown in Figures 2 through 6. Usually in the second, third and in some cases, through the fifth cycle, the curves shifted toward higher values of gassing rates. Beyond the fifth cycle and through the twelfth cycle, the curves were approximately the same as observed for the first cycle.

A comparison of the gassing rate data as a function of the state of charge for the fifth and twelfth cycles, is shown in Table 4. The gassing rate values are taken from smoothed curves drawn through the original data points. It can be seen that the gassing values for the originally low capacity electrodes (141, 121, and 82) overlap the values for the original high capacity electrodes (128, 74, and 45). The other observation that can be made is that a given electrode shows a trend to lower gassing values with increasing cycles. This result may be partially due to the increasing capacity value with cycling.

IMPURITY STUDY

After the twelfth cycle, carbon dioxide was bubbled through the electrolyte of the test cells containing electrodes 74, 128, 141 and 121. Carbonate content was determined by acid titration to a phenolphtalein end point and then to a methyl red end point. Cycling was then continued for an additional six cycles to note differences in capacity and gassing behavior of the positive electrodes. These data have not been completely analyzed and will be reported in the next progress report. The carbonate content level added to these cells was approximately 0.3 molar. There was no large capacity variation noted from an examination of capacity values in the fourteenth cycle (see Figures 2 through 6).

The scope of impurity study is outlined in Table 5. The procedure to be followed in these tests was presented in the second quarterly progress report.

Figure 2. Positive Electrode Gas Evolution Rate Versus State of Charge.

100% Depth of Discharge - Charge and Discharge Rate 300 ma.
Two Consecutive Cycles Followed by Several Days Rest

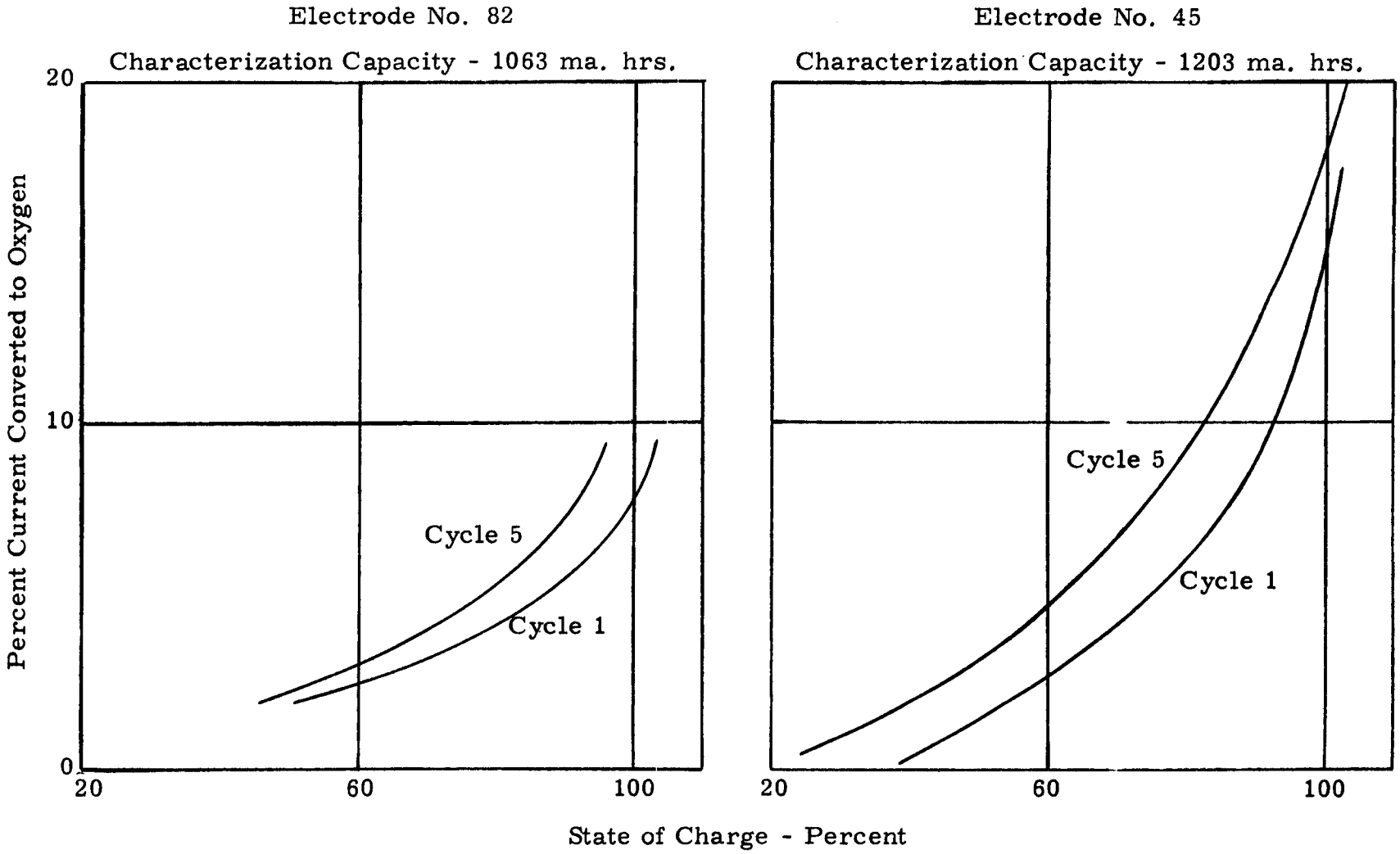

Figure 3. Positive Electrode Gas Evolution Rate Versus State of Charge.

100% Depth of Discharge - Charge and Discharge Rate 300 ma.
Six Consecutive Cycles Followed by Several Days Rest

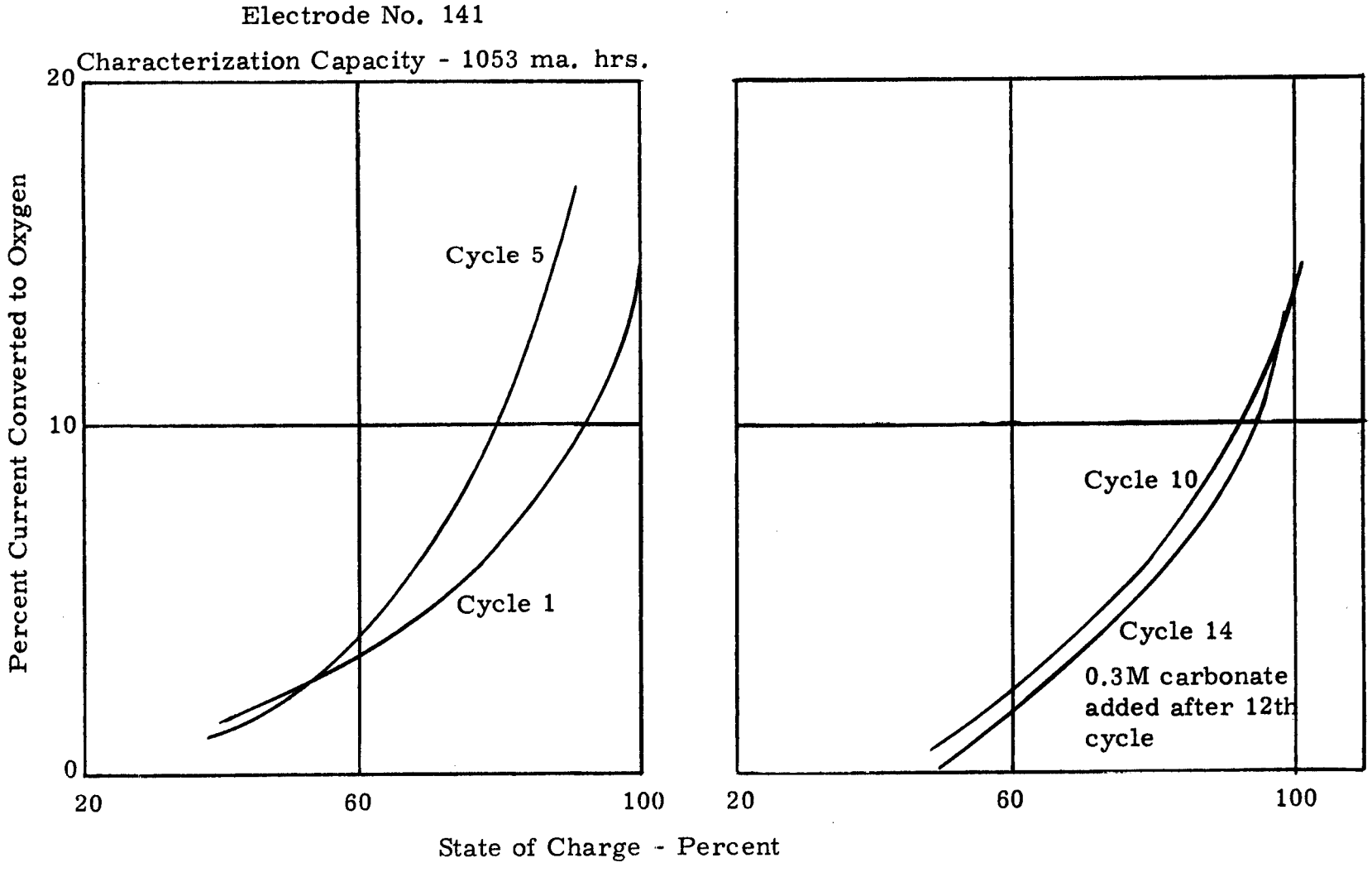

Figure 4. Positive Electrode Gas Evolution Rate Versus State of Charge.

100% Depth of Discharge - Charge and Discharge Rate 300 ma.
Six Consecutive Cycles Followed by Several Days Rest

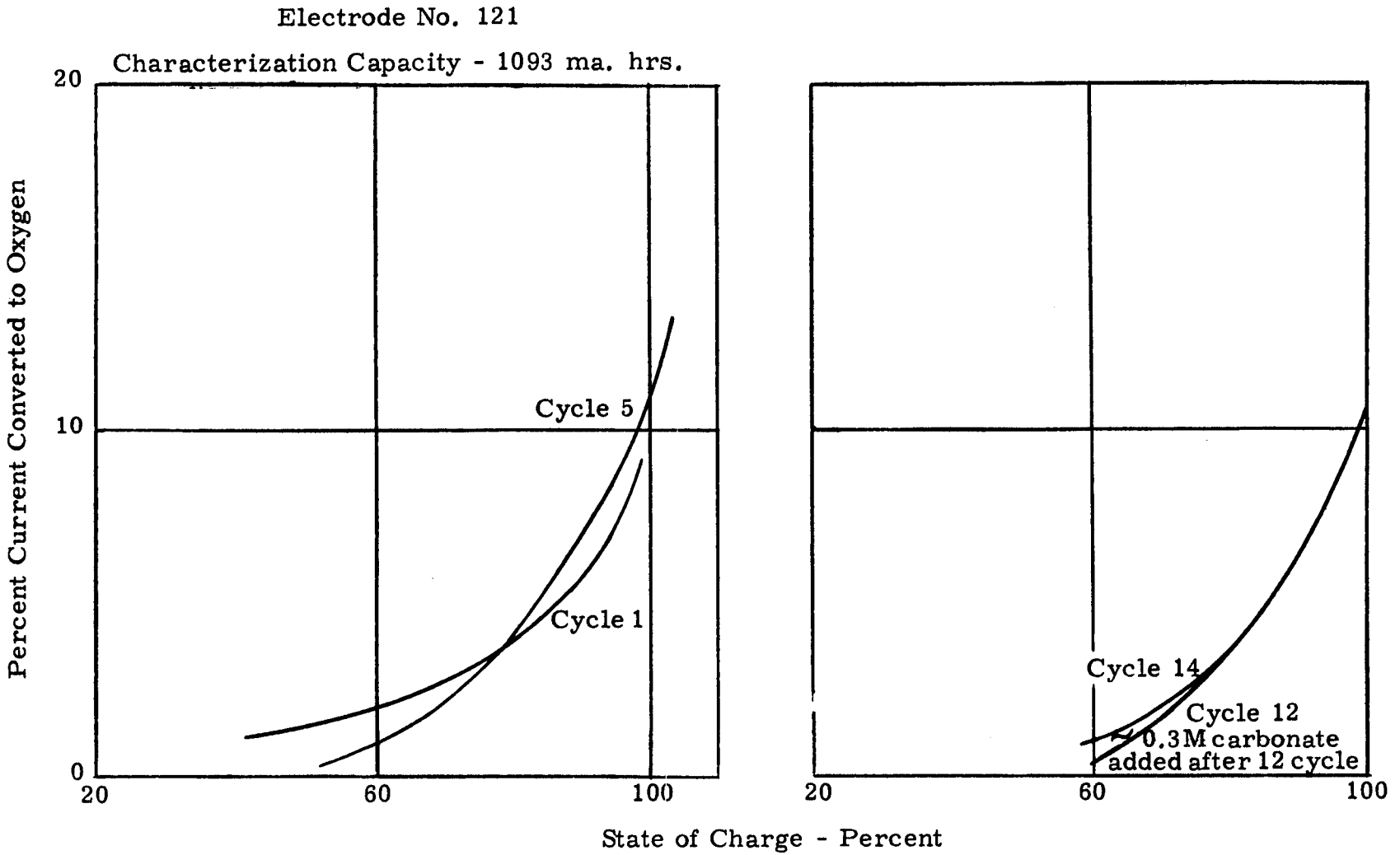

Figure 5. Positive Electrode Gas Evolution Rate Versus State of Charge.

100% Depth of Discharge - Charge and Discharge Rate 300 ma.
Six Consecutive Cycles Followed by Several Days Rest

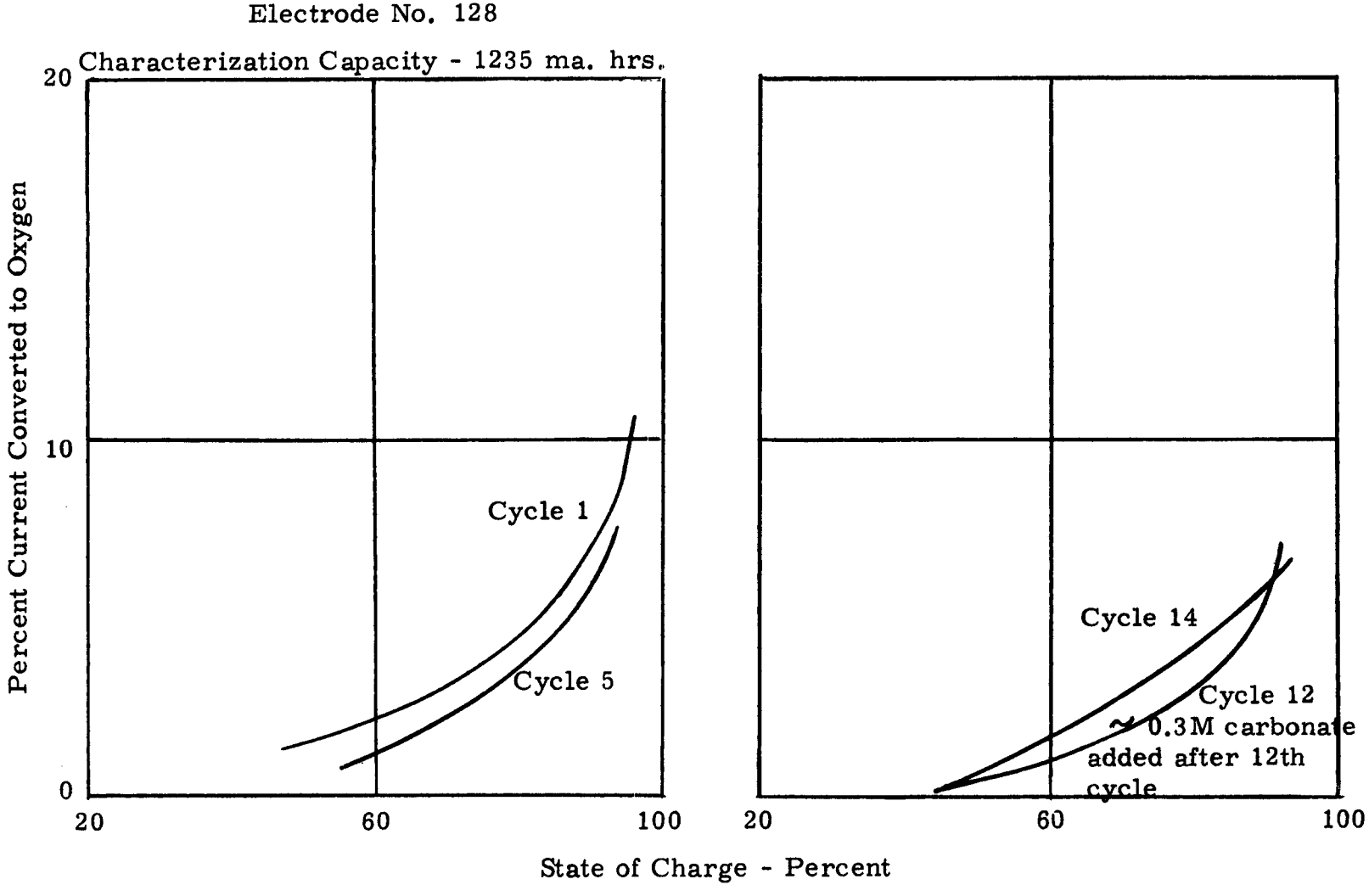

Figure 6. Positive Electrode Gas Evolution Rate Versus State of Charge.

100% Depth of Discharge - Charge and Discharge Rate 300 ma.
Six Consecutive Cycles Followed by Several Days Rest

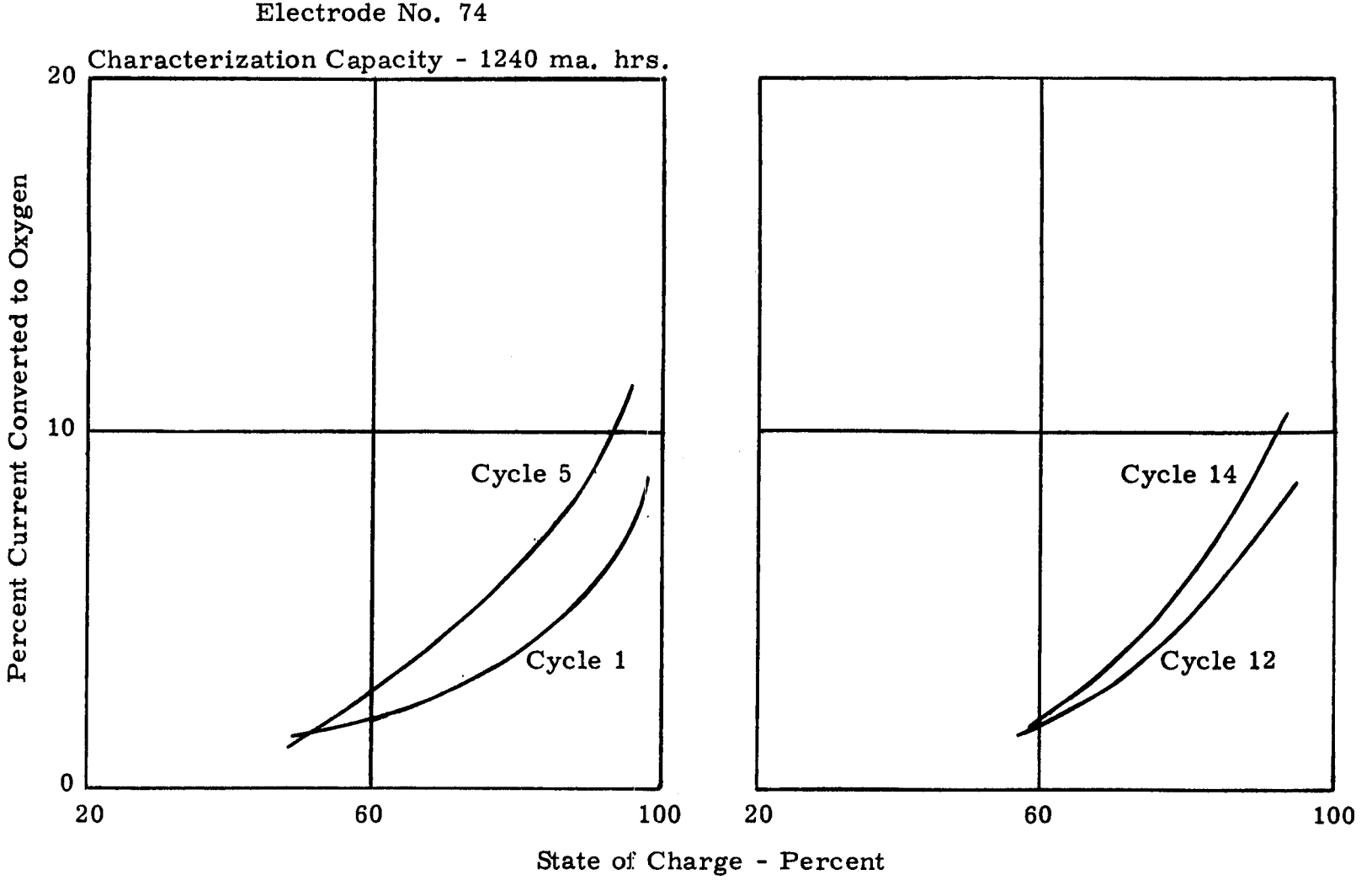

TABLE 4

POSITIVE ELECTRODES GASSING DATA COMPARISON

Electrode Number	Initial Characterization Capacity ma.hrs.	Cycle	Capacity For Cycle ma.hrs.	Percentage of Current Converted to Oxygen State of Charge Factor-% 60	80	90
128	1235	5	1260	1.2	3.5	5.8
		12	1290	1.2	3.1	5.4
74	1240	5	1236	2.6	6.2	8.8
		12	1269	1.8	4.7	7.0
45	1203	5	1162	4.8	9.3	12.8
141	1053	5	1125	3.9	10	15.6
		12	1200	2.4	4.7	7.0
121	1093	5	1146	6.8	4.0	6.8
		12	1230	6.3	3.7	6.5
82	1063	5	1162	3.0	5.4	7.3

TABLE 5

IMPURITIES TO BE INVESTIGATED

Source	Primary	Secondary
Manufacturing		
Plate	NO_3^-, $CO_3^=$	Cr, Al, Na
	$Fe^{\overset{+++}{\underset{++}{}}}$, Cu, Ag	
Electrolyte	$SO_4^=$, Cl^-	$CO_3^=$, $SiO_4^=$, Na, Hg
	Li	
	Organic Wetting Agents	
Construction Materials	Kel F	--
Degradation in Operation		
Corrosion	Fe, Al_2O_3,	--
	Ag	
Separators and Other Materials	Epoxy Carboxy-methyl cellulose Nylon Polypropylene	--

Section 3

PROGRAM FOR NEXT QUARTER

The work on the positive electrode behavior studies will include the testing of electrodes in the 100% and 25% depth of discharge cycling mode. Comparisons will be made between electrodes characterized for six cycles and for some characterized 25 cycles.

Electrodes of these types will also be screened for short term effects of various levels of impurities in the electrolyte.

At the start of this program, the Battery Business Section was unable to supply us with a sufficient quantity of proper grade plate material for use in the program. Plate material was received in September, 1965. This delay has caused our program schedule to slip four months. An extension in time only is being requested by our contract administrator.

APPENDIX I

TABLE I-1

CAPACITY DATA FOR CHARACTERIZED ELECTRODES

Electrode Number	Average Discharge Capacity (ma.hrs.)	Slope (ma.hrs./cycle)	Average Graphitic Capacity (ma.hrs.)	Slope (ma.hrs./cycle)
152	997	- 3.0	110	25.7
172	1031	-15.0	191	33.0
122	1045	-12.0	140	25.7
132	1035	- 5.1	130	26.6
159	1042	- 5.6	152	28.7
197	1027	- 2.1	100	18.9
183	1015	- 3.4	137	23.6
184	1027	0.4	95	15.4
194	1027	0.4	82	18.4
148	1030	0.0	105	25.7
149	1015	5.1	197	27.9
133	1065	- 7.7	140	24.9
135	1075	- 6.0	140	21.4
165	1086	- 7.5	129	25.5
177	1080	- 6.0	111	28.5
125	1060	- 6.0	152	26.1
140	1085	- 6.0	175	29.1
167	1056	- 7.5	171	37.5
193	1060	- 4.3	70	13.7
105	1090	- 1.7	95	15.4
174	1080	- 4.5	87	18.0
155	1085	- 3.4	95	20.6
131	1092	- 3.9	140	19.7
163	1095	- 4.5	114	19.5
187	1077	- 0.4	112	17.6
195	1055	- 1.7	122	19.3
121	1092	- 3.9	125	21.4
145	1085	- 3.4	117	20.1
117	1052	- 2.1	145	28.3
141	1052	- 2.1	127	28.7
158	1085	0.0	85	16.3
142	1095	4.3	92	20.1
198	1060	1.7	85	20.6
182	1097	1.3	130	13.7
175	1089	1.5	102	24.0
192	1080	2.6	120	24.9
139	1087	0.4	177	25.3
151	1077	5.6	165	19.7
168	1080	10.5	156	46.5
154	1082	26.1	92	21.0

TABLE I-1 (con't)

CAPACITY DATA FOR CHARACTERIZED ELECTRODES

Electrode Number	Average Discharge Capacity (ma.hrs.)	Slope (ma.hrs./cycle)	Average Graphitic Capacity (ma.hrs.)	Slope (ma.hrs./cycle)
101	1115	-10.3	97	18.4
111	1115	-10.3	157	28.7
124	1142	- 7.3	95	9.4
123	1120	- 8.6	95	13.7
115	1120	- 0.9	90	11.1
156	1122	- 2.1	57	14.1
176	1134	- 4.5	93	16.5
138	1132	- 2.1	95	21.4
126	1132	- 3.9	137	-21.9
200	1147	- 3.9	147	4.7
129	1147	- 3.9	115	12.0
164	1107	- 1.5	117	18.0
189	1150	- 0.0	130	16.3
146	1125	- 4.3	105	25.7
171	1116	- 3.0	150	31.5
150	1122	- 2.1	160	22.3
104	1127	- 2.1	160	30.0
185	1127	0.4	90	13.7
143	1130	6.0	90	14.6
169	1107	7.5	99	21.0
178	1113	10.5	132	36.0
144	1125	26.6	127	29.6
191	1155	-18.0	157	14.1
162	1176	-12.0	99	15.0
173	1158	- 7.5	108	21.0
181	1157	- 0.4	77	8.1
153	1170	- 4.3	90	18.9
179	1155	- 4.5	90	19.5
199	1187	- 3.0	142	4.7
160	1162	- 2.1	140	18.0
130	1157	- 1.3	135	24.0
114	1155	- 0.9	120	27.4
161	1161	- 3.0	126	30.0
112	1155	- 4.3	160	13.7
180	1200	- 3.0	156	12.0
102	1155	- 4.3	167	17.6
116	1170	- 0.9	195	20.6
157	1197	0.4	87	17.6
190	1175	2.6	147	4.7
188	1157	2.1	130	25.7
186	1155	9.4	92	5.6

TABLE I-1 (con't)

CAPACITY DATA FOR CHARACTERIZED ELECTRODES

Electrode Number	Average Discharge Capacity (ma.hrs.)	Slope (ma.hrs./cycle)	Average Graphitic Capacity (ma.hrs.)	Slope (ma.hrs./cycle)
147	1155	7.7	67	11.6
170	1152	7.5	75	15.0
136	1160	5.1	127	-18.4
196	1200	9.4	137	12.4
137	1167	26.1	125	21.4
109	1242	-12.4	185	12.9
128	1235	- 5.1	122	15.0
113	1210	- 5.1	150	15.4
166	1239	- 4.5	105	15.0
134	1207	- 3.9	115	18.9
103	1232	- 1.3	167	14.1
120	1247	- 3.9	190	15.4
107	1235	0.0	140	14.6
106	1217	2.1	195	11.1
119	1280	-18.9	177	15.9
118	1270	1.7	127	29.6
108	1275	6.0	190	22.3
215	1012	- 3.9	137	21.9
290	1020	- 2.6	225	30.0
282	1045	6.0	127	26.1
202	1070	-11.1	110	17.1
217	1080	-11.1	120	18.0
242	1100	-11.1	130	18.0
211	1095	- 6.9	120	14.6
220	1082	- 7.3	117	12.4
245	1082	- 6.4	150	30.9
297	1092	- 5.6	140	31.7
260	1080	- 6.9	182	28.7
228	1092	- 2.1	135	23.1
234	1100	- 0.9	142	22.7
251	1077	- 3.0	145	23.1
236	1082	- 2.1	147	27.9
244	1052	- 2.1	130	30.0
250	1052	- 2.1	192	29.6
281	1077	- 1.3	152	28.7
230	1052	- 2.1	215	26.6
312	1085	- 0.9	240	28.3
237	1090	1.7	127	26.1

TABLE I-1 (con't)

CAPACITY DATA FOR CHARACTERIZED ELECTRODES

Electrode Number	Average Discharge Capacity (ma.hrs.)	Slope (ma.hrs./cycle)	Average Graphitic Capacity (ma.hrs.)	Slope (ma.hrs./cycle)
252	1082	1.3	140	27.4
233	1060	1.7	140	30.9
210	1090	0.0	200	27.4
311	1096	3.3	161	28.2
313	1072	0.4	252	26.1
212	1150	-11.1	100	14.6
201	1125	- 9.4	112	12.4
207	1115	- 9.4	107	15.0
248	1127	- 5.6	112	26.1
300	1140	- 6.9	157	28.7
316	1122	- 5.6	152	29.6
287	1132	- 5.6	162	34.7
318	1120	- 5.1	170	34.3
219	1110	- 2.6	95	14.6
257	1135	- 1.7	97	21.9
293	1107	- 4.7	97	21.9
231	1147	- 2.1	140	20.6
232	1150	- 1.7	142	21.0
296	1140	0	140	28.3
226	1132	- 2.1	162	22.7
227	1145	0.9	97	19.3
255	1132	3.0	107	21.9
317	1140	1.7	145	23.1
238	1132	3.9	182	27.9
306	1107	1.3	160	30.9
240	1142	4.7	252	11.6
292	1120	8.6	117	13.3
224	1125	6.9	145	25.7
284	1120	12.9	172	35.6
314	1140	30.0	145	37.5
291	1162	-27.0	195	13.7
205	1157	- 8.1	97	11.6
222	1200	- 8.6	100	11.1
206	1195	- 7.7	105	9.4
208	1180	- 7.7	145	7.7
216	1170	- 7.7	112	9.9
210	1172	- 7.3	107	10.7
218	1167	- 9.9	122	15.0
241	1157	- 6.4	127	12.4
209	1180	- 7.7	157	4.7
295	1165	- 5.1	152	32.1

TABLE I-1 (con't)

CAPACITY DATA FOR CHARACTERIZED ELECTRODES

Electrode Number	Average Discharge Capacity (ma.hrs.)	Slope (ma.hrs./cycle)	Average Graphitic Capacity (ma.hrs.)	Slope (ma.hrs./cycle)
249	1197	- 1.3	95	7.7
283	1190	- 3.4	125	12.9
221	1162	- 2.1	132	15.0
243	1195	- 3.4	150	17.1
235	1170	0	147	25.3
246	1170	- 4.3	172	15.9
253	1190	- 0.9	157	15.9
258	1195	- 2.6	162	15.9
298	1197	- 3.0	172	16.7
320	1180	- 4.3	165	19.7
315	1162	1.3	130	24.9
301	1195	5.1	122	11.6
289	1180	6.0	110	17.1
294	1167	16.7	130	23.1
204	1202	- 6.4	147	6.4
213	1222	- 5.6	115	5.1
203	1202	- 3.9	120	7.7
214	1217	- 3.0	147	6.4
247	1212	- 4.7	137	15.0
223	1202	- 2.1	132	18.4
256	1215	- 4.3	125	19.7
254	1235	- 1.7	170	13.7
307	1225	- 2.6	200	13.7
225	1230	0	162	15.9
285	1202	- 2.1	175	18.0
309	1207	- 3.0	157	21.0
286	1225	0.9	167	19.3
259	1202	5.6	100	3.4
302	1265	- 6.0	177	12.4
303	1260	- 4.3	170	13.7
305	1255	- 3.4	167	12.4
319	1272	- 4.7	197	12.4
308	1280	1.7	132	9.0
229	1255	3.4	162	11.6

TABLE I-2

Positive Electrode Gas Evolution Data

Electrode Number 45

Initial Characterization Capacity 1203

Cycling Mode -- 100% Depth of Discharge - 300 ma. Charge and Discharge Rate at Room Temperature

Total Cycles 6 -- Two Consecutive Cycles with Several Days Rest in Between

Cycle Number and Capacity (ma. hrs.)	Electrode State of Charge %	Current Into Oxygen %	Cycle Number and Capacity (ma. hrs.)	Electrode State of Charge %	Current Into Oxygen %
1-1144	13.1	0	4-1141	13.1	0
	26.2	.33		26.3	.67
	39.2	1.1		39.2	2.2
	52.2	2.1		52.0	4.3
	65.1	3.4		64.7	7.3
	77.9	5.5		77.2	11.0
	90.5	8.8		89.5	16.8
	102.6	17.5		101.5	25.0
2-1161	12.9	0	5-1162	12.9	0
	25.8	.23		25.8	.67
	38.7	.93		38.5	1.6
	51.4	2.3		51.2	3.3
	64.0	4.4		63.8	5.7
	76.5	6.9		76.2	8.0
	88.8	11.5		88.5	12.3
	100.3	25.0		103.3	20.0
3-1162	25.8	0	6-1162	12.9	0
	38.7	.83		25.8	.33
	51.4	2.0		38.6	1.3
	64.1	3.3		51.3	3.0
	76.7	5.2		63.8	5.3
	89.1	9.0		76.2	8.7
	100.9	18.7		88.4	12.7
				100.2	21.7

TABLE I-2

Positive Electrode Gas Evolution Data

Electrode Number 74

Initial Characterization Capacity 1240

Cycling Mode -- 100% Depth of Discharge -- 300 ma. Charge and Discharge Rate at Room Temperature

Total Cycles 18 -- Six Consecutive Cycles with Several Days Rest in Between ~0.3 M Carbonate Added after Cycle 12

Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %	Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %
1-1194	25.1	0	5-1236	24.3	0
	37.7	.33		36.4	.17
	50.1	1.3		48.5	1.0
	62.5	2.3		60.4	2.7
	74.9	3.0		72.2	4.7
	87.2	5.0		84.0	7.0
	99.4	8.3		95.6	10.3
2-1230	24.4	0	12-1269	23.6	0
	36.5	1.0		35.5	.17
	48.5	2.7		47.2	.77
	60.3	5.0		58.9	1.7
	72.1	7.3		70.5	3.0
	83.8	10.3		82.1	5.3
	95.3	16.7		93.4	7.8
3-1230	24.4	0	14-1269	23.6	0
	36.5	.33		35.5	.17
	48.6	1.7		47.2	.60
	60.6	3.3		58.9	1.8
	72.4	5.7		70.5	3.8
	84.2	7.7		81.9	6.0
	96.0	10.7		93.3	8.8
4-1230	24.4	0			
	36.6	.33			
	48.7	1.3			
	60.7	2.7			
	72.6	4.0			
	84.4	7.0			
	96.1	10.3			

TABLE I-2

Positive Electrode Gas Evolution Data

Electrode Number 82

Initial Characterization Capacity 1063

Cycling Mode -- 100% Depth of Discharge -- 300 ma. Charge and Discharge Rate at Room Temperature

Total Cycles 6 -- Two Consecutive Cycles with Several Days Rest in Between

Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %	Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %
1-1144	13.1	0	4-1162	25.8	0
	26.2	.23		38.7	.50
	39.2	1.0		51.4	2.3
	52.2	2.0		63.9	4.7
	65.1	2.9		76.4	7.0
	78.0	4.2		88.8	10.0
	90.9	5.5		101.1	14.3
	103.6	9.4			
2-1161	12.9	0	5-1236	24.3	0
	25.8	.17		36.4	1.0
	38.7	.67		48.3	2.0
	51.5	2.2		60.2	3.3
	64.0	4.2		72.1	4.3
	76.6	6.3		84.1	6.0
	89.0	9.2		95.8	8.6
	101.3	13.8			
3-1180	25.4	0	6-1236	12.1	0
	38.1	.50		24.3	.33
	50.7	1.1		36.3	.67
	63.3	2.0		48.4	1.3
	75.8	3.3		60.3	3.3
	88.2	5.3		72.1	5.3
	100.5	8.3		83.8	7.7
				95.5	11.0

TABLE I-2

Positive Electrode Gas Evolution Data

Electrode Number 121

Initial Characterization Capacity 1093

Cycling Mode -- 100% Depth of Discharge -- 300 ma. Charge and Discharge Rate at Room Temperature

Total Cycles 18 -- Six Consecutive Cycles with Several Days Rest in Between ~0.3 M Carbonate Added After Cycle 12

Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %	Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %
1-1050	14.3	0	5-1146	39.3	0
	28.5	.33		52.3	.33
	42.8	1.0		65.3	1.3
	56.9	2.0		78.1	3.3
	71.0	2.7		90.8	6.0
	85.0	4.7		103.2	11.7
	98.7	8.7			
2-1104	13.6	0	6-1155	39.0	0
	27.2	.17		51.9	.33
	40.7	.67		64.8	1.3
	54.1	2.0		77.6	2.7
	67.2	7.3		90.2	5.7
	79.8	10.7		102.1	10.3
	92.8	13.0			
3-1116	13.4	0	12-1230	24.4	0
	26.8	0		48.8	.2
	40.3	.17		60.9	.5
	53.6	.83		73.0	2.2
	66.9	2.0		84.8	4.8
	79.8	7.3		96.4	9.0
	92.3	10.7			
	105.1	14.7			
4-1128	13.3	0	14-1230	24.4	0
	26.6	0		48.8	.20
	39.9	0		60.9	1.0
	53.2	.33		72.9	2.7
	66.4	1.3		84.7	4.7
	79.4	3.7		96.4	9.0
	92.2	6.0			
	104.8	12.3			

TABLE I-2

Positive Electrode Gas Evolution Data

Electrode Number 128

Initial Characterization Capacity 1235

Cycling Mode -- 100% Depth of Discharge -- 300 ma. Charge and Discharge Rate at Room Temperature

Total Cycles 18 -- Six Consecutive Cycles with Several Days Rest in Between. ~0.3 M Carbonate Added After Cycle 12

Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %	Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %
1-1230	24.4	0	5-1260	35.7	0
	36.6	.33		47.6	.33
	48.7	1.3		59.4	1.0
	60.7	2.0		71.2	2.7
	72.7	3.7		82.8	4.0
	84.6	5.3		94.3	7.3
	96.2	11.0			
2-1245	36.1	0	12-1290	23.3	0
	48.2	.67		46.5	.33
	60.0	2.7		58.1	.87
	71.7	4.3		69.5	2.2
	83.5	6.0		81.0	3.2
	95.0	12.7		92.3	6.2
3-1250	36.0	0	14-1290	23.3	0
	48.0	.33		46.5	.33
	59.9	1.3		58.0	1.1
	71.7	3.0		69.5	2.6
	83.3	5.0		80.8	4.2
	95.0	7.3		92.2	6.5
4-1257	35.8	0			
	47.7	.33			
	59.5	1.3			
	71.3	2.7			
	83.0	4.3			
	94.5	7.3			

TABLE I-2

Positive Electrode Gas Evolution Data

Electrode Number 141

Initial Characterization Capacity 1053

Cycling Mode -- 100% Depth of Discharge -- 300 ma. Charge and Discharge Rate at Room Temperature

Total Cycles 18 -- Six Consecutive Cycles with Several Days Rest in Between ~0.3 M Carbonate added after Cycle 12

Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %	Cycle Number and Capacity (ma.hrs.)	Electrode State of Charge %	Current Into Oxygen %
1-1035	14.5	0	5-1125	13.3	0
	29.0	.33		26.7	.17
	43.3	1.7		39.9	1.0
	57.5	3.0		53.0	2.7
	71.7	4.7		66.0	5.3
	85.7	8.0		78.7	9.0
	99.3	14.0		91.0	16.3
2-1080	13.9	0	10-1176	25.5	0
	27.8	.17		38.3	.17
	41.6	1.0		50.9	1.0
	55.2	3.0		63.5	3.0
	68.6	6.0		75.8	5.0
	81.9	9.3		88.1	8.5
	94.7	17.0		100.1	13.3
3-1104	13.6	0	14-1200	25.0	0
	27.2	.17		37.5	.10
	40.6	1.3		50.0	.40
	53.9	3.3		62.3	2.0
	67.1	6.0		74.5	4.2
	80.0	9.7		86.5	7.0
	92.5	18.7		98.3	12.8
4-1110	13.5	0			
	27.0	.17			
	40.5	1.0			
	53.7	2.7			
	66.8	5.3			
	79.8	9.0			
	92.3	16.3			